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Personalizable Lighting System

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The project PETAL is cofunded by the Active and Assisted Living Programme (AAL-2016) and the following National Authorities and R&D programs in Italy, Spain, Austria and Romania.

1 INTRODUCTION

This deliverable describes the personalizable lighting system that was developed for the project PETAL.

"Personalizable Lighting" is a term that has become more and more popular in the lighting industry during the last years. Although the term is almost omnipresent and nearly everyone uses this term with confidence, there is no precise definition what is meant by "personalizable lighting", and more in general with "personalization". In the Human-Computer Interaction area, two main approaches are considered for personalization (see e.g. Findlater and McGrenere, 2004): *adaptive interfaces*, which dynamically adjust the interface in a way that is intended to support the user; and *adaptable* interfaces, which provide customization mechanisms but rely on the user to use those mechanisms to do the adaptation. Thus, these approaches differ with respect to *who* is in control of the personalization: adaptive interfaces are system-controlled, whereas adaptable interfaces are user-controlled. An easy example of *adaptive* system in real life is Google, which learns about the interests of an end-user, and then adapts its offered results to user preferences by learning from the past. The system builds up an individual profile for each user which is further expanded in dependency of the users' behaviour.

With specific reference to the project PETAL and its lighting features, till now in the PETAL project only end-users can choose which kind of lighting features and which light products they need from a given pool. Therefore, on the one hand, the PETAL lighting system is now mainly *adaptable* and scalable to user's personal needs since it requires that end users specify the kind of customisations to use (through the rules). On the other hand, an *adaptive* lighting system would mean that the lighting system gathers information about a user, builds up a user profile and adapts lighting according to this profile. In PETAL we plan to provide a more adaptive support in future developments by using e.g. some machine-learning algorithms able to analyse various information gathered about the user (in terms of e.g. data provided by sensors, rules created by users) and, according to this information, be able to suggest possible e.g. lighting-based personalizations to users.

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2 PETAL Lighting System

The PETAL Lighting System was developed to support elderly with MCI and their formal or informal caregivers in their activities of daily live in their homes as well as to provoke positive effects on the patients' health and the caregivers' burden. Lighting that addresses positive health effects in human beings is usually described by Human Centric Lighting (HCL). This term was implemented in 2013 into the lighting industry and describes all kinds of lighting that positively affect human beings' mood, alertness, performance, health and wellbeing. Usually the following components are considered: 1) use of daylight, 2) high-quality artificial light supplementing daylight whenever it is missing, 3) use of sensors to optimize light usage and 4) easy-to-use light control schemes.
With the new LED-technology, luminaires that fulfil the HCL-approach can be developed and penetrate the lighting market. But there are still gaps for new luminaires with special features and functions for specific user groups e.g. patients with cognitive declines. PETAL addresses patients with Mild Cognitive Impairment (MCI), an early stage of dementia that also comes along with impairments in memory functions, spatio-temporal orientation, alertness, planning and problem solving. A market analysis conducted by Bartenbach in 2018 showed that there is no mobile light solution that fits these goals and can be used easily by this target group in their home settings. Therefore, Bartenbach developed a new standing-luminaire for another AAL-project (GREAT – Get Ready for Activity – Ambient day scheduling with dementia) in cooperation with *emt*, a Swiss partner and expert in electronics. This luminaire fulfils all requirements that are addressed in the PETAL project as well. But, because one luminaire is not enough to equip a whole flat with about 4 rooms as is aimed in PETAL, a product analysis was performed to find out which products can be added to fit the PETAL project goals. The PETAL-lighting system should be very flexible and adaptable in modularity and scalability to fulfil the needs of a customer.
We defined the following requirements as crucial for the lighting system:

1) All components must be available at the market
2) All components must be easily installable
3) All components must have an internet connection to connect it with the PETAL platform
4) The whole PETAL system must cost below 4000 EUR.

The product analysis resulted in a lighting system consisting of different Philips lighting components and a standing-luminaire from Bartenbach & emt (see Figure 1 and Figure 2). In addition, daylight sensors will be used to gather information about the current light levels at important locations.

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Figure 1 GREAT-luminaire

Figure 2 Philips Hue White ambiance and Philips Hue light stripe white and colour ambiance

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The advantages of this lighting concept are, that no electric knowledge is necessary to install the components as well as that the system is easy to dimension to fit different flat architectures with different sizes of rooms.

The PETAL Lighting System components were chosen to reach specific light effects (see

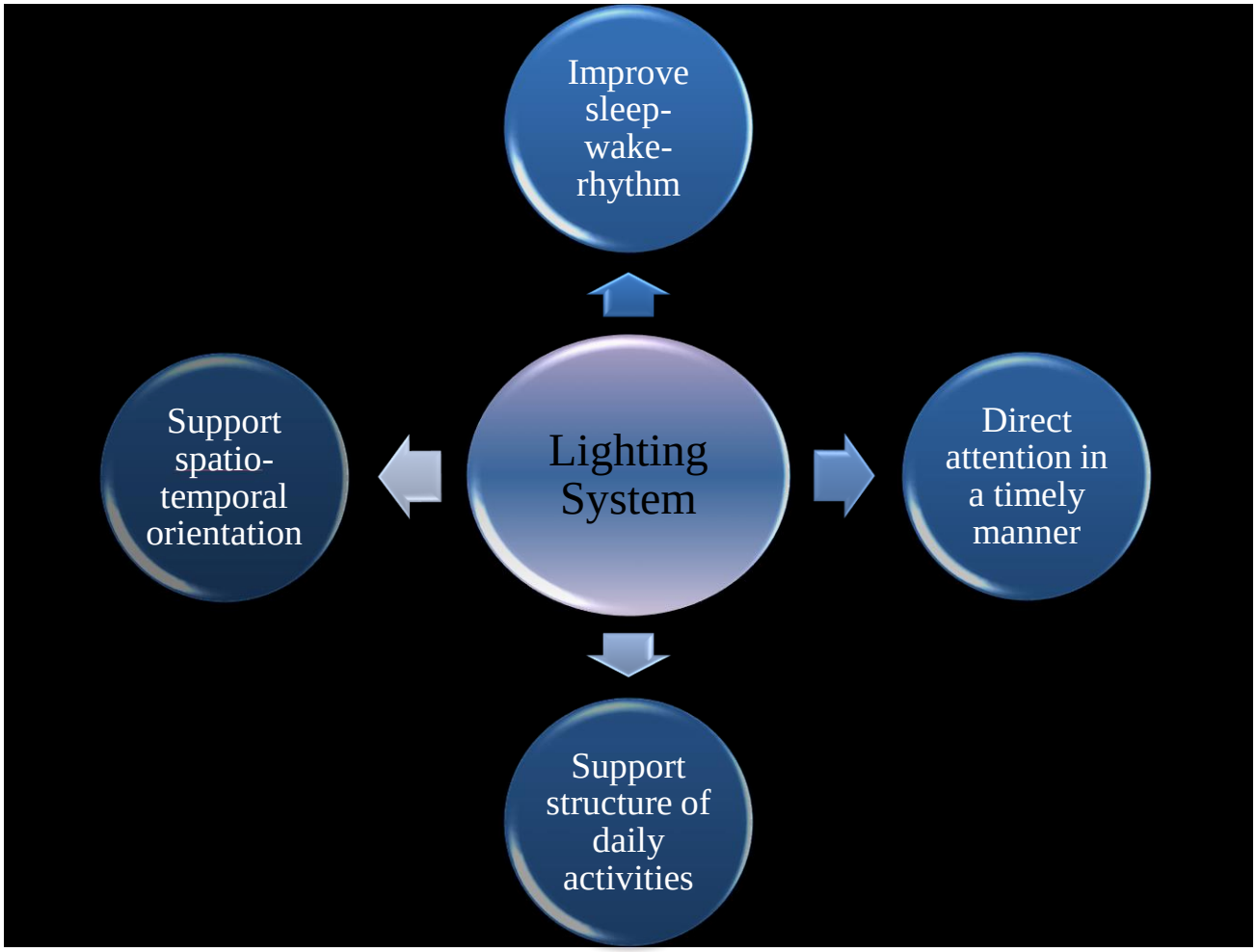

Figure 3), namely to improve the sleep-wake-rhythm, to direct attention in a timely manner, to support the structure of daily activities and to support spatio-temporal orientation.

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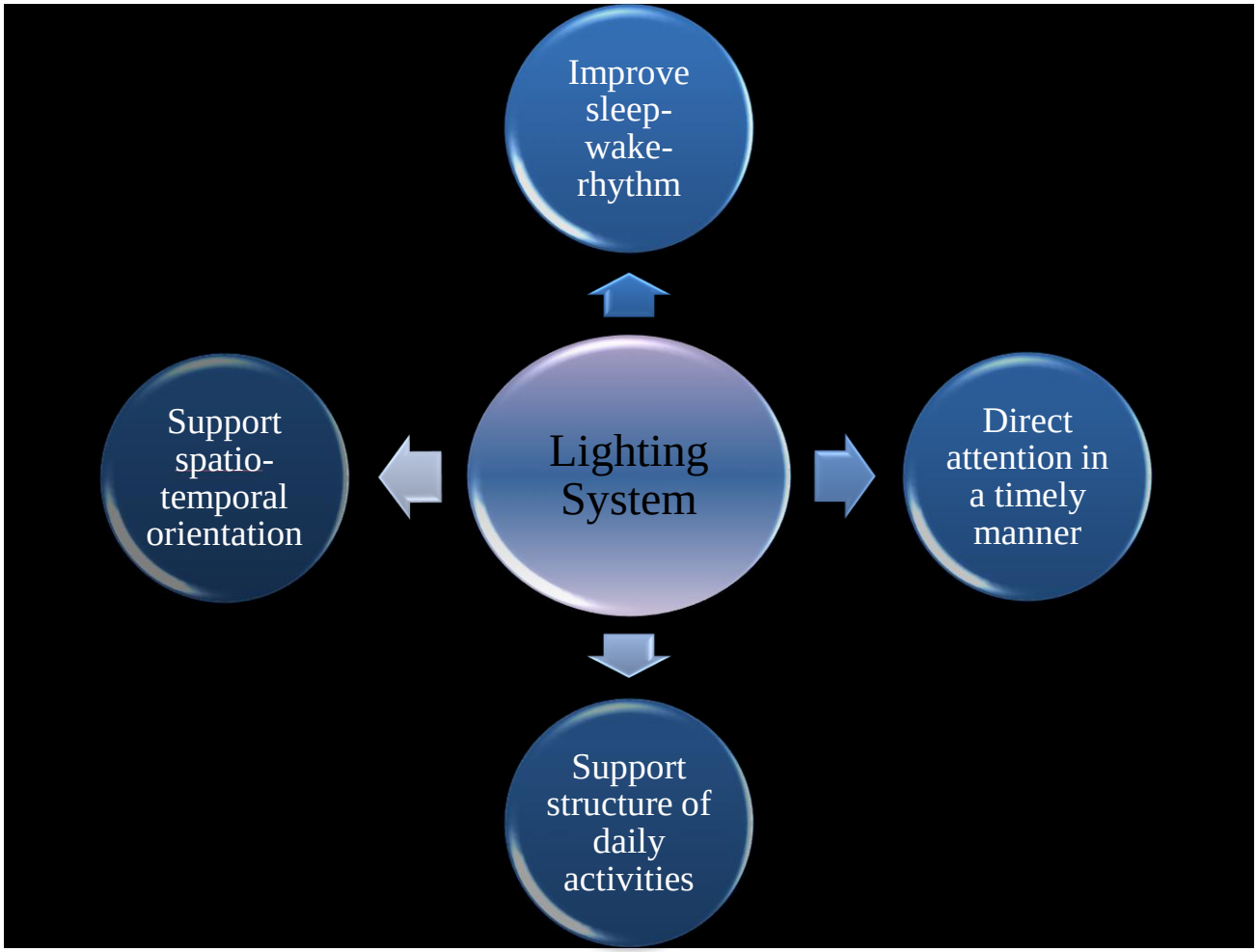

Figure 3 Expected light effects

Improve sleep-wake-rhythm:
To improve the sleep-wake-rhythm we use different colour temperatures and illuminance levels at different times of the day. In detail, this means that the whole flat will provide a colour temperature of 4000 K during the daytime and 2700 K during the night time. Different scientific papers showed that high colour temperatures during the night cause melatonin suppression [e.g. Higuchi et al. 2016], which may lead to an interruption of the sleep-wake-rhythm. Therefore, lower colour temperatures should be used during the night. We expect positive effects especially on the stabilization of the sleep-wake-rhythm which is moderated by the endocrine system, meaning to prevent the observers from melatonin suppression during the night that leads to chronodisruption (disruption of the internal clock that controls the sleep-wake-cycle). Melatonin is a hormone,

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that plays an important role in moderating sleep-wake-states and it supports the transition from being awake to sleep. Sleep problems like frequent interruptions of sleep as well as problems falling asleep are quite common in the elderly population which is a result of zeitgeber-weakness (light is the strongest zeitgeber on human being's sleep-wake-rhythm) and biological degradation of the human being's eye with increased age. In order to improve zeitgeber-strength, bright light with a high colour temperature (e.g. 4000 K) will be provided during the day and reduced light levels with lower colour temperature will be provided during the late evening and night. If the mobility of a person makes it possible, daylight will also be used to improve the sleep-wake-rhythm. Daylight is the brightest light source that is available and therefore is the most efficient zeitgeber. But if a person's mobility is reduced, missing daylight can be supplemented by artificial bright light inside a flat.

Direct attention in a timely manner:
Light attracts attention and light has an influence on the acute alertness level of human beings (see Yang et al., 2018). We can use this knowledge to guide the attention of an observer by using daylight or artificial light signals. For artificial light white or coloured light can be used.

Support structure of daily activities:
Usually our daily activities follow a more or less stable time schedule. We wake up, wash ourselves, eat breakfast, do some activities (do household, work, do some hobbies, etc.), eat lunch, do some more activities, eat dinner, relax, go to bed, sleep. When people stop working because of retirement or because they suffer from different diseases, this rhythm starts to decompose. This frequently leads to sleep problems, energy loss during the day and mood disturbances like depression. Beside using daylight, artificial light can be used to support and maintain a regular day schedule by providing different light settings for different times of the day and specific activities. Basically, a biodynamic light curve will be used, that varies in colour temperature and light intensity in a 24 hours rhythm. In the morning people will wake up with slowly increasing light levels that starts with low relaxing colour temperature (warm white, "orange" light) and ends with high activating colour temperatures (cold white, "bluish" light). During the day activating light with high colour temperature will be provided to support daily activities and, in the evening a slow reduction in light levels and colour temperature prepare observers for going to sleep. Beside biodynamic lighting, ambient light scenes and light cues can be used to support specific activities e.g. bright, high quality light improves visual comfort and therefore eases visual tasks or moving around safely. Light cues can also be used to make a person aware of

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important activities e.g. turning on the light in the kitchen at lunch time remembers a person about preparing a meal and eat at the right time.

Support spatio-temporal orientation:
People with MCI often have problems with spatial and/or temporal orientation. Light can be used to help patients finding the right place easier and at the right time. e.g. finding the bathroom during the night faster. Biodynamic light gives a person a natural information of the time of day, when temporal orientation is impaired e.g. bright light means that it is during the day, low intensity melatonin light means that it is during the night.

In the project PETAL we will use different kinds of lighting to reach the above described effects: daylight; artificial light with melatonin light, orientation light, wake up light and signal light. Figure 4 summarizes the different used kinds of lighting and the expected effects. In sum they are creating the PETAL lighting concept.

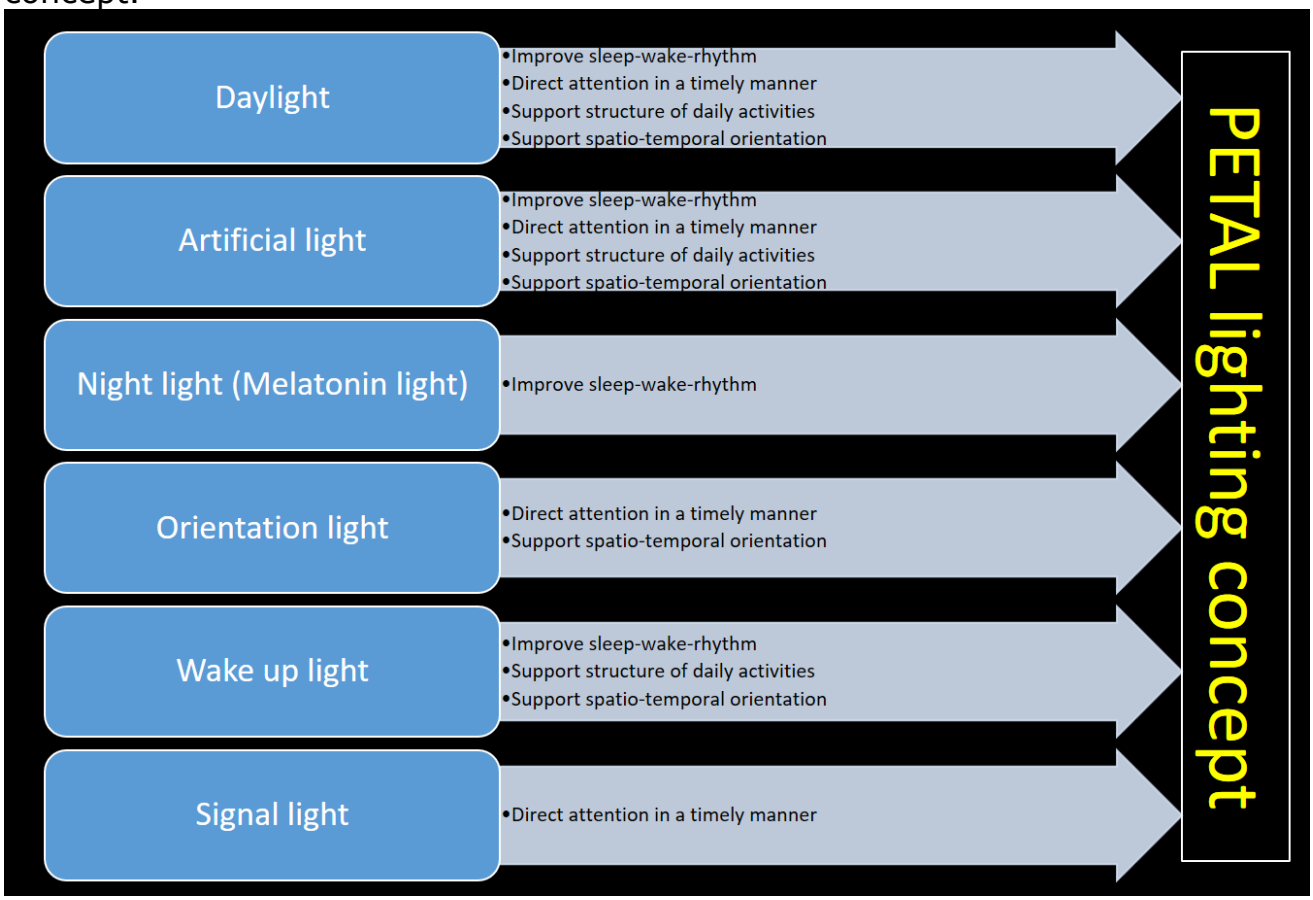

Figure 4 PETAL lighting concept - used lights to reach specific effects

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In order to fulfil the expected visual and non-visual effects products had to be found that fits to our project goals. In a first step, photometrical requirements for the products were defined (see Table 1 Technical specifications for the PETAL Lighting System). A market analysis on lighting products and their availability was carried out as a basis for the correct product choice. The inclusion criteria for the products are described above.

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Table 1 Technical specifications for the PETAL Lighting System. CCT…Correlated Colour Temperature in Kelvin, Eh…horizontal illuminance in lux (=amount of light striking a surface measured horizontally at a surface e.g. at the surface of a table), Ev…vertical illuminance in lux (=amount of light striking a surface measured vertically e.g. at the eyes of a standing observer)

Requirements	Technical specifications	Location (room)	Sensors
Use of daylight to stabilize activity-rest-patterns	Daily light dosage of 5000lxh should be reached	Indoor and outdoor	Daylight sensors
Good artificial light for higher visual requirements	Eh_{table} = 1000lx, glarefree	Living room (most common place)	-
Activating ("light shower") and relaxing light cues to guide behaviour	see GREAT cues: activation Ev=600 lx CCT = 4000 K, relaxation Ev=120 lx, CCT = 2700 K	Living room (most common place)	Daylight sensor
Wake up light for stabilization of sleep-wake-cycle	Eh_{max} = increasing to approx. 200lx CCT = increasing from 2200 to 4000 K	Bed room	-
Changes in CCT to provide stabilization of sleep-wake-cycle	CCT_{Day} = 4000 K, CCT_{Night} = 2200 K	Whole flat; exception kitchen: CCT_{Night}=2700 K	-
Orientation light to guide person safely during the night	Eh_{floor} = 25 lx dimmable	Bed room	Movement sensor (presence/absence)
Signal lighting to guide attention	Approx. 300lx White and coloured light (RGB…red green blue)	Living room (most common place)	-

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Light detection to prevent unwanted events	-	Bath room	Light sensor, movement sensor

2.1 PETAL Lighting System Components - detailed description

The PETAL Lighting System consists of the following components:

1) Philips hue white ambiance bulb:

The Philips hue white ambiance bulb provides different colour temperatures between 2200 and 6500 K (detailed technical specifications see Figure 6). This range of correlated colour temperature is necessary to prevent people from melatonin suppression during the night (2200 K) and gives a strong "zeitgeber"-signal during the day (>4000 K). The bulbs are easy to install, because old bulbs only need to be replaced, which means that participants can carry their "old" lamps, but with better light sources. Another advantage of the Philips hue is, that it is easy to integrate into the CNR web platform and has an open protocol to control the light functions. Furthermore, Philips provides an own Hue bridge and a dim switcher to control the bulbs (see Figure 5). At last, Philips hue components are always available and, in comparison to other products at the market, cheap.

Figure 5 Philips hue Bridge, Bulbs White ambiance (2200-6500 K) and dim switcher

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The bulb

Fitting	E26
Form factor	A19
Lifetime	25000 hour(s)
Color temperature	2200K-6500K
Wattage	10 W
Input voltage	110V-130V
Lumen output	806 lm @ 4000K
Software upgradable	Yes
Start up	Instant 100% light output
Height	109 mm
Height	4.3 inch
Max. operation power	10 W
Max. standby power	0,1 W
Diameter	62 mm
Diameter ?	2.4 inch
Light output	Warm white to cool daylight

The bridge

Height	1 inch
Height	26 mm
Frequency band	2400~2483.5 MHZ
Max. number of accessories	12
Max. number of bulbs	50
Mounting options	Wall
Power adapter	100–240 V AC / 50–60Hz
Length X Width ?	3.5 x 3.5 inch
Length X Width ?	88 x 88 mm

What's supported

IOS	Yes
HomeKit compatible	Yes
iPad	Yes
iPad Air	No
iPad Mini	No
iPhone	Yes
iPod Touch	No

Figure 6 Philips hue white ambiance bulb technical specifications

2) <u>Philips hue LED-LightStrip Plus:</u>

The Philips hue LED-LightStrip Plus is a flexible LED-Stripe with 2 metre in length. It is extendable or can be shortened in dependency of the room geometry. It comes with 1.600 lm and is adjustable in tuneable white (warm white – cold white) and 16 million colours (for product specifications see Figure 8). Therefore, it can be perfectly used to provide additional light in task areas e.g. below cupboards in the kitchen or to guide someone from one room to another or to provide coloured light signals e.g. if someone has forgotten to take his medicine a short red light shows that something is wrong – the information about what is wrong appears at the tablet. In addition, the light

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is dimmable, so that it can be used to provide low level orientation light during the night without glaring a person.

Figure 7 Philips hue Lightstrip Plus

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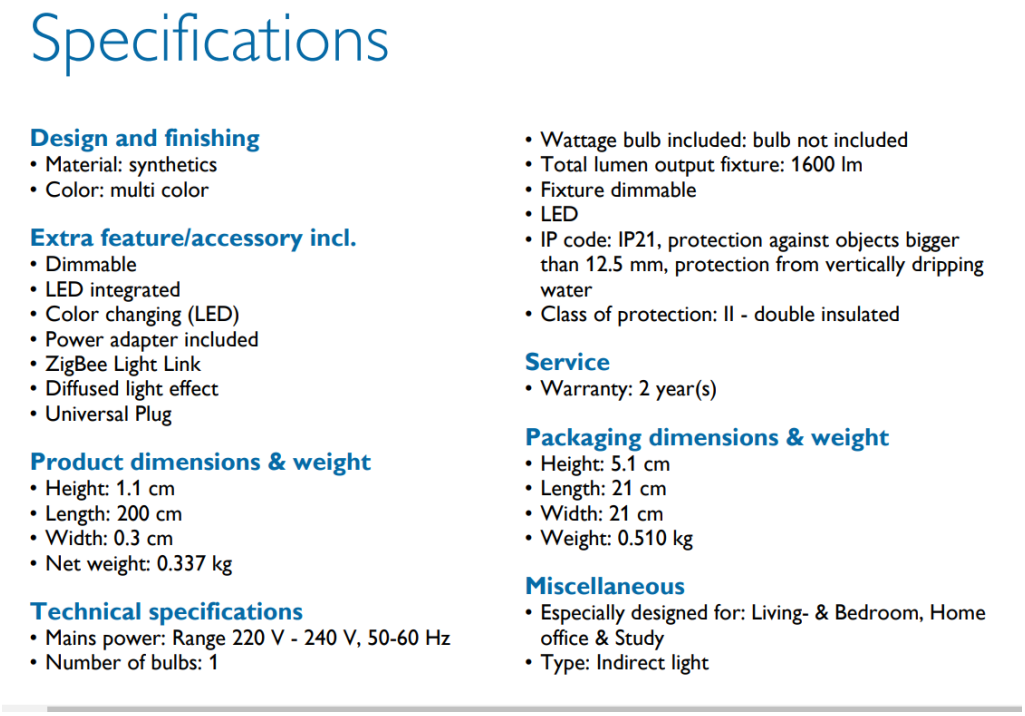

Specifications

Design and finishing
- Material: synthetics
- Color: multi color

Extra feature/accessory incl.
- Dimmable
- LED integrated
- Color changing (LED)
- Power adapter included
- ZigBee Light Link
- Diffused light effect
- Universal Plug

Product dimensions & weight
- Height: 1.1 cm
- Length: 200 cm
- Width: 0.3 cm
- Net weight: 0.337 kg

Technical specifications
- Mains power: Range 220 V - 240 V, 50-60 Hz
- Number of bulbs: 1
- Wattage bulb included: bulb not included
- Total lumen output fixture: 1600 lm
- Fixture dimmable
- LED
- IP code: IP21, protection against objects bigger than 12.5 mm, protection from vertically dripping water
- Class of protection: II - double insulated

Service
- Warranty: 2 year(s)

Packaging dimensions & weight
- Height: 5.1 cm
- Length: 21 cm
- Width: 21 cm
- Weight: 0.510 kg

Miscellaneous
- Especially designed for: Living- & Bedroom, Home office & Study
- Type: Indirect light

Figure 8 Philips hue LightStrip Plus product specifications

3) GREAT-Luminaire:

The GREAT-Luminaire was developed during another AAL project at Bartenbach to influence the affective state of people with dementia. The goals were to activate or relax people with dementia in specific situations or to prepare them for upcoming actions. The luminaire homogenously illuminates a whole room with up to 25m^2 and it consists of three light components:

1) Uplight: indirect light for ambient room illumination
2) Downlight: diffuse task-light for facial brightening
3) Flexible spot: direct task-light for high visual requirements in the task area.

The uplight fills the room with light with a unique homogenous light sky and provides high illuminance levels at a persons' eye level (=amount of light striking the humans' eye, measured vertically at the eye) via reflection of light from the ceiling and the walls. With a light flux of about 10.000 lm (=quantity of light emitted by a light source) only for the uplight the GREAT-Luminaire provides light intensities that are, applied over some hours,

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similar to light intensities applicated by light therapy and therefore provides health provoking effects especially on mood and sleep-wake-rhythm.

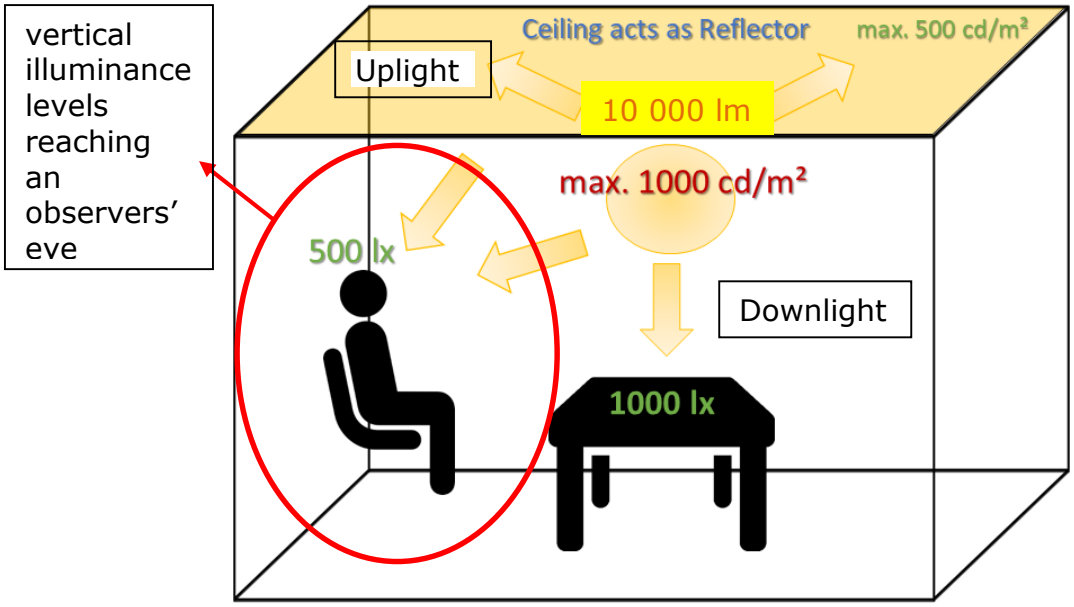

Figure 9 Light concept of the GREAT-Luminaire: light intensities at an observers' eye will be reached by illuminating the ceiling as light reflector – therefore the light source provides more than 10 000 lm (light flux). Additionally, a downlight is used to light the task area and to add some more light at the observers' eye. Reducing the luminance level to max. 1000 cd/m2 insures that the light source is glare free for the observer.

The downlight provides a diffuse light at the task area and adds to the ambient lighting to brighten faces, which is important for people talking with each other. Finally, up to two flexible spots can be added to the luminaire to provide a spotlight at specific task areas, where more light is needed. The spots are flexibly adjustable by the user itself. The expected biological

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effects that are addressed by the GREAT-luminaire are described in the following.

Figure 10 GREAT-luminaire

Biological effects:
The GREAT-luminaire was developed to provide a unique light concept (see Figure 11) incorporating a biodynamic light approach with high light intensities during the day, a high-quality light for higher visual requirements especially in elderly and different light scenes leading to activation or relaxation.

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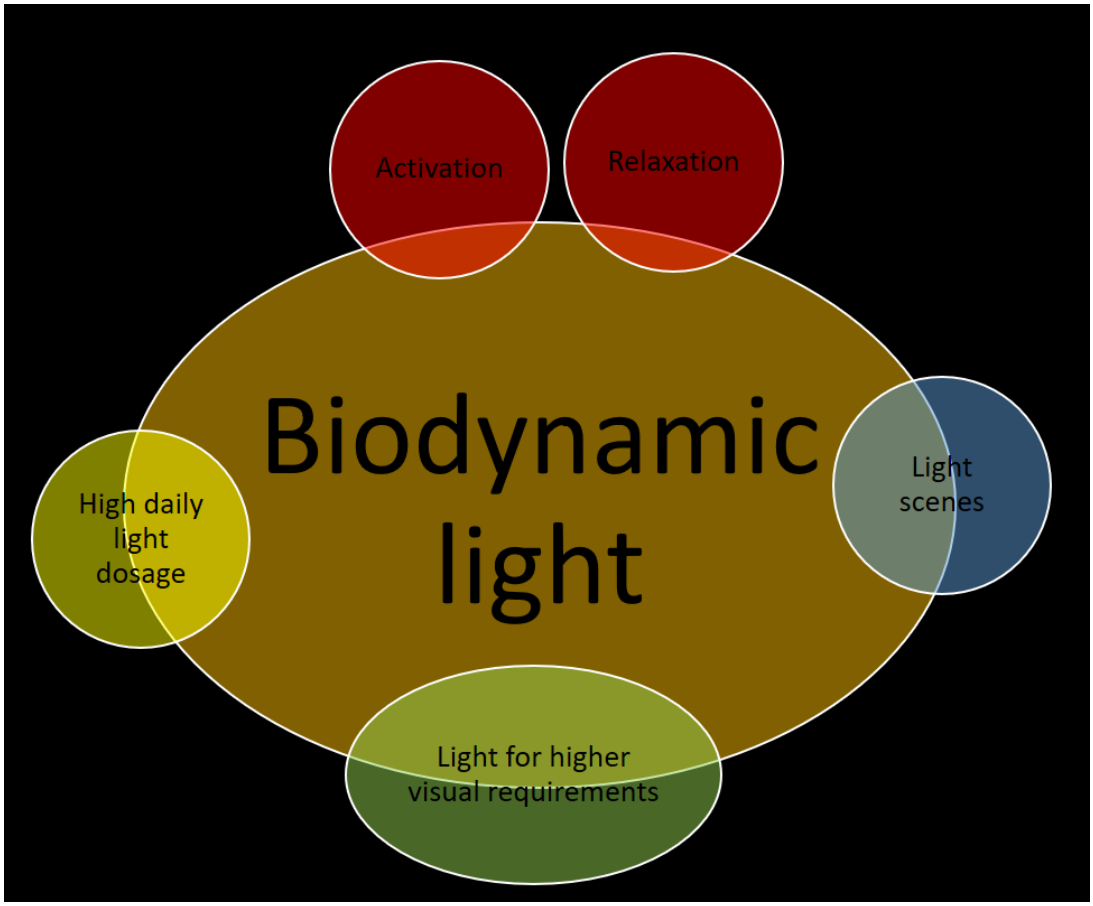

Figure 11 GREAT - light concept

1) Biodynamic light

a) Reaching a high, daily light dosage – 5000lxh vertical at the eye level to maintain and strengthen health

Because of the three components (uplight, downlight, spotlight) the luminaire reaches very high light levels of about 1000lx at the eye level if an observer sits below the luminaire. In comparison to light therapy devices where a person needs to sit directly in front of it, the same light dosage will be reached freely moving within the room in about 5 hours. A high light dosage is usually used to improve mood disturbances and to stabilize the sleep-wake-cycle.

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a) Variable colour temperature during 24 hours for strengthening the day-night-cycle

The luminaire provides colour temperatures ranging from 2200 until 5000 K. 2200 K do not disturb the release of the sleep hormone melatonin during the late evening and night. 5000 K are representing daylight and therefore give a strong day-time signal to the body. This high colour temperature is activating and avoids feeling sleepy. Slow changes between this to ends of the spectrum combined with changing light intensities are simulating dusk and dawn and therefore provide a light setting simulating the natural light from the sun, which is very comfortable.

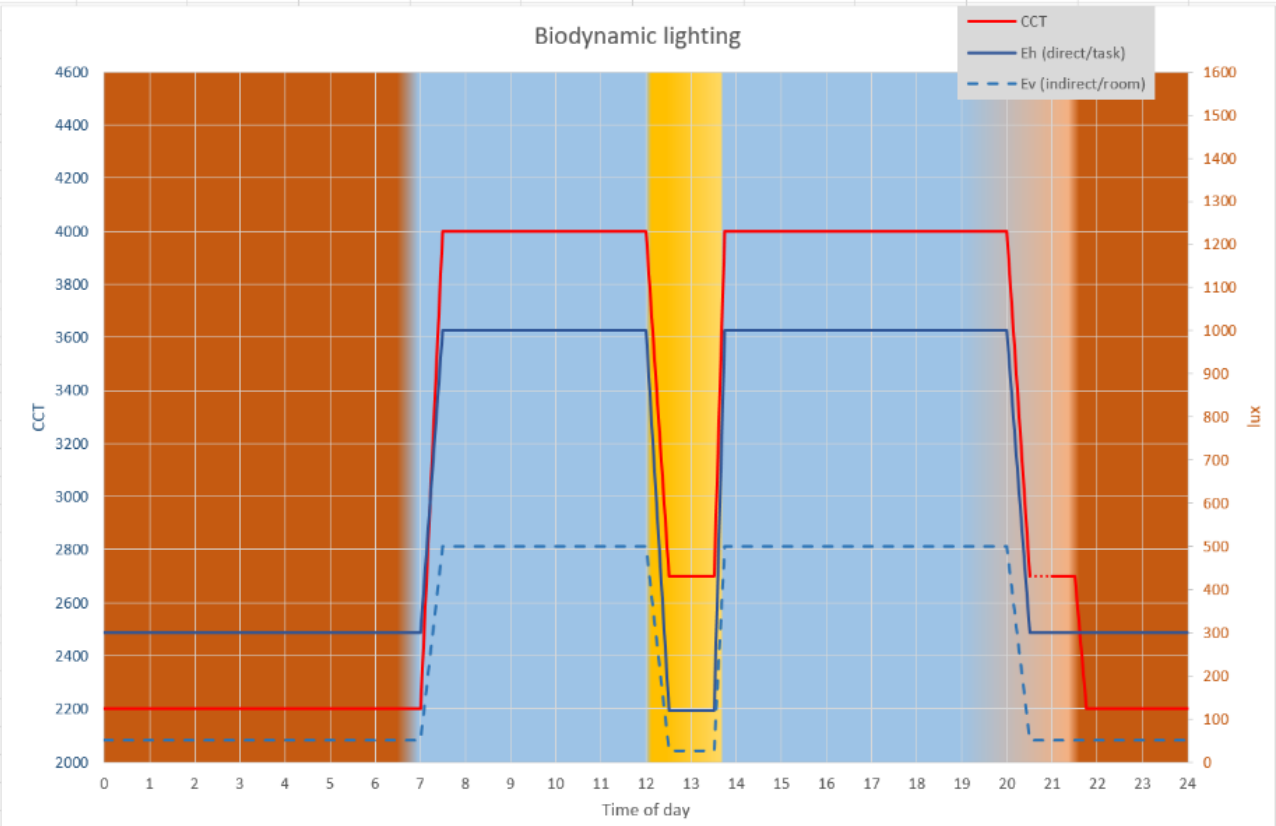

Figure 12 Biodynamic light curve over 24 hours [CCT…colour temperature in Kelvin, illuminance in lux]

2) <u>Ambient light scenes for activation and relaxation</u>

The GREAT-Luminaire comes with special light scenes that were developed to have an influence on the acute affective state of an observer. The user can choose between an activating light cue, a relaxing light cue and a "TV"-scene:

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- Activating light cue: studies showed that light with specific colour temperature and intensity can be used for acute alerting effects (Yang et al., 2018).

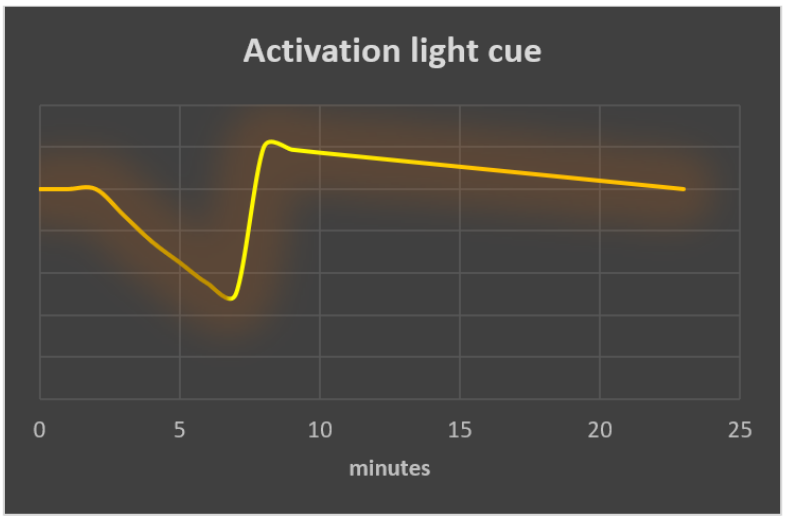

Figure 13 Activating light cue

- Relaxing light cue: a reduction in light intensity and colour temperature directly lead to a feeling of comfort and relaxation.

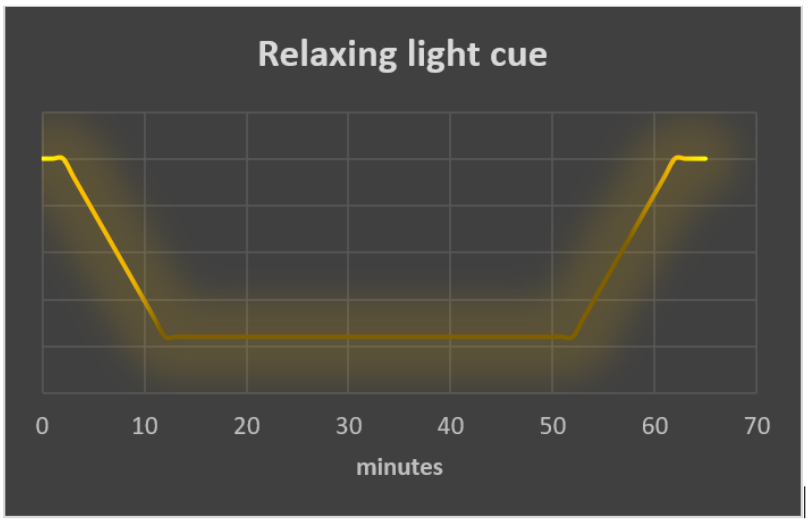

Figure 14 Relaxing light cue

- "TV"-scene: a relaxing ambient light setting for activities with low visual demands e.g. while listening to music or watching TV.

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3) High-quality light for higher visual requirements coming with age

The GREAT-Luminaire fulfils the highest quality criteria currently attainable with technological possibilities:

- Illuminance levels in the task area:
  0.3 < $E_{cylindric}/E_{horizontal}$ < 0.6 at eye level and at height of desk [DIN EN12464]

- maximal luminance in range of vision:
  1000 cd/m² (avoids glare)
  [ANSI /IESNA RP-28-07 recommendation]

- horizontal illuminance levels in task area:
  day = 1000 Lux; night < 300 Lux

- spectral quality
  CRI = 90

- avoidance of **multishadows**

- PWM-dimming frequency
  >1,25 kHz
  [IEEE1789 recommendation]

Figure 15 summarizes the positive effects on people with MCI addressed by using the GREAT-luminaire in the project PETAL.

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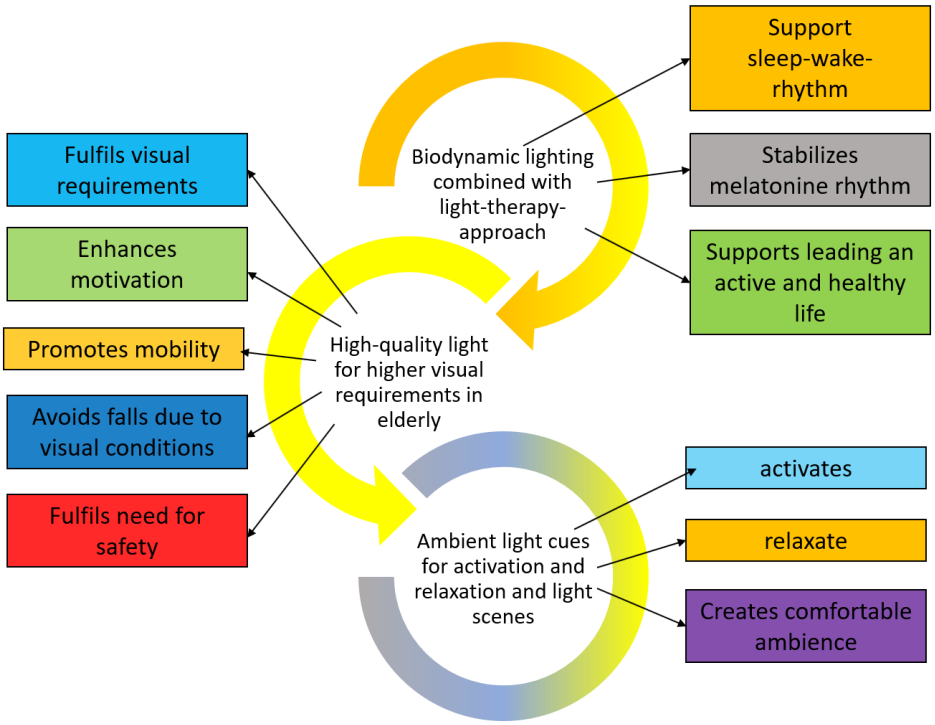

Figure 15 Light effects of the GREAT-concept

2.2 Prototype-flat equipment

The lighting components will be used to equip a whole flat with 4 rooms: bedroom, living room, kitchen and bathroom (see Figure 16). The GREAT-Luminaire will be installed in the most common place e.g. the living room or the kitchen because the GREAT-Luminaire is able to provide light therapy and different light scenes and we expect the most important effects on health from it. Since it is a mobile standing-luminaire, in order to get the best effects, we simply need to position it at the right place. The Philips Hue bulbs will be used in all the other rooms. This insures that colour temperature can be adjusted in the whole flat within a 24 hours rhythm with high colour temperatures during the day and melatonin enhancing light during the night. Light stripes will be additional used to provide better light at task areas in the kitchen, to provide a signal in the living room and to guide a person from the bedroom to the bathroom during the night.

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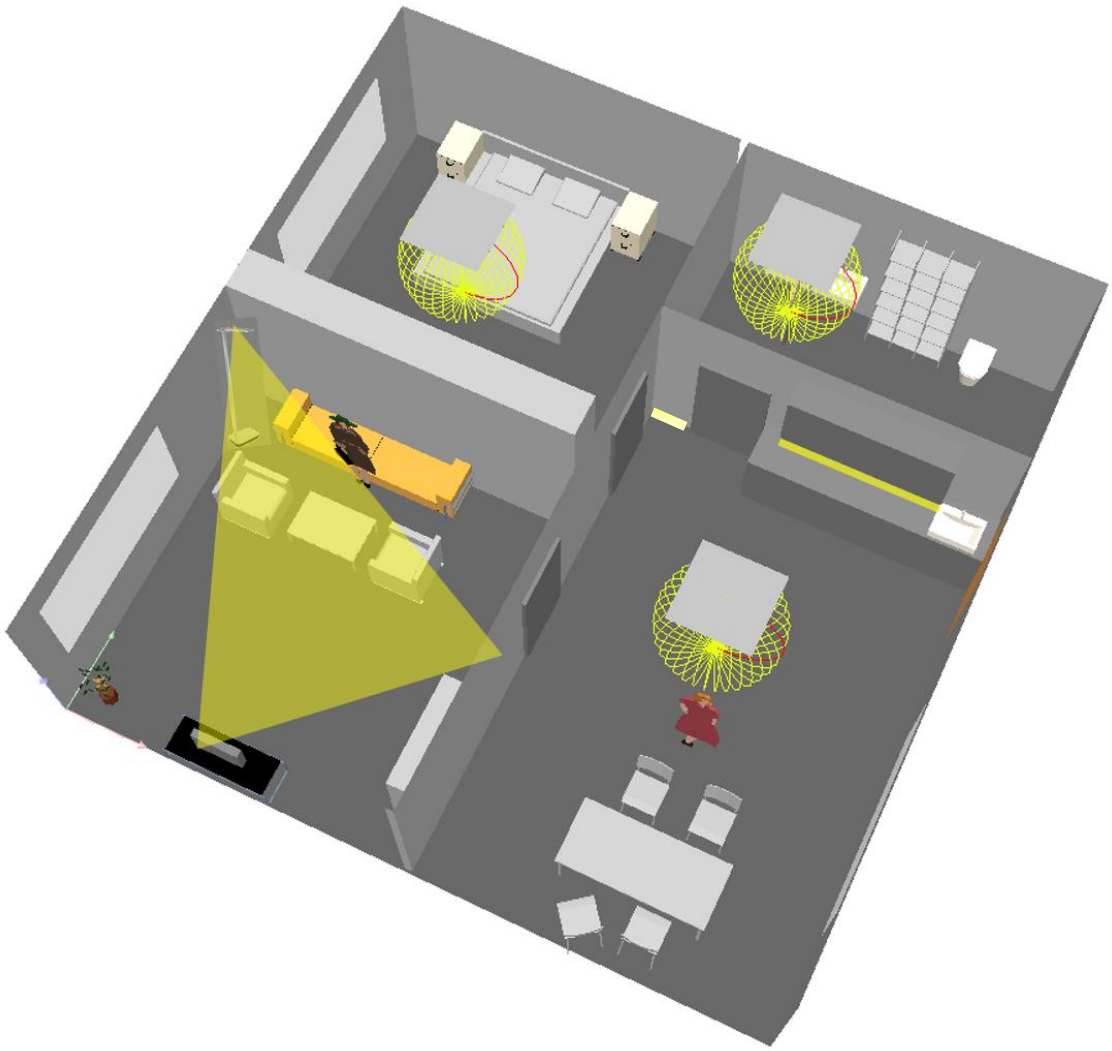

Figure 16 Prototype-flat with GREAT-Luminaire in the living room and bulbs in all other rooms. Additionally, light stripes are used in the kitchen under cupboards for the task areas and at floor level to guide someone from one room to another

2.3 PETAL Lighting System – Cost calculation

Table 2 shows the detailed cost calculation for the whole PETAL - lighting system for one flat with 4 rooms (bedroom, living room, kitchen and bathroom). Beside the lighting components, the hue bridge, motion sensors with integrated daylight sensors and dimmers are included in the calculation.

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Table 2 PETAL - Lighting system - cost calculation

Location	Application	Counts	Price per unit
Bedroom	Philips Hue white ambiance bulb	1	30,00
	Orientation light for bedroom Philips Hue LightStrip Plus, 2m + Aluminium profile 2m	1	85,00
Living room	Great luminaire	1	2000,00
	Signal lighting, Philips Hue LightStrip Plus, 2m + Aluminium profile 2m	1	85,00
Kitchen	Philips Hue white ambiance bulb	1	30,00
	Task lighting for kitchen, Philips Hue LightStrip Plus, 2m + Aluminium profile 2m	1	85,00
Bathroom	Philips Hue white ambiance bulb	1	30,00
	Signal lighting, Philips Hue LightStrip Plus, 2m + Aluminium profile 2m	1	85,00
Accessories	Philips Hue bridge	1	45,00
	Philips Hue Motion Sensor with built in Daylight Sensor	5	35,00
	Philips Hue Wireless Dimming Device	4	22,00 /53,00
Price Total	**2760,00**		

2.4 Integration of Lighting System into PETAL-web platform

Integration was carried out by CNR on the basis of provided information on lighting devices by Bartenbach. Communication is based on HTTP-protocol.

The lighting concept was designed in order to fulfil required possible rules, that can be useful to support MCI patients in their daily living and to reduce caregiver's burden. As the analysis of requirements performed in workpackage 1 showed, the potential of light is often underestimated in the context of care. For this reason, some examples of rules were already created, which can be suggested to the end-users (Table 3).

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Table 3 Possible lighting rules

Rule no.	Rule name	Trigger	Action
1	Use daylight outside	IF there is bright daylight	THEN remember person to go outside
2	Use daylight inside	IF daylight is insufficient at the most common place (e.g. couch)	THEN remember person to go to brighter areas in the flat
3	Use artificial bright light	IF there is not enough daylight in the flat	THEN artificial light should turn on
5	Wake up smoothly with light	IF the person should be waked up	THEN the wake-up light turns on
6	Use alarm light for oven	IF the oven has left on after leaving the kitchen	THEN the signal light should turn on (red alarm)
7	Inform caregiver in emergency case	IF there is light in the bathroom during the night for more than 2 hours	THEN give an alert message to his/her caregiver/relative
8	Prevent falling at night	IF the person stands up during the night	THEN the orientation light turns on guiding the way to the bathroom
9	Healthy biodynamic light	IF the person is inside the flat	THEN biodynamic light will be used in all occupied rooms

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3 Conclusion

For the PETAL project a lighting system consisting of light products already available at the market was designed. The selection criteria contented the following:

1) All components must be available at the market
2) All components must be easily installable
3) All components must have an internet connection to connect it with the PETAL platform
4) The whole PETAL-system must cost below 4000 EUR.

After a huge market analysis and a product search we selected different lighting components from the Philips hue series and a luminaire, developed by Bartenbach & emt in another AAL project. The expected effects for end-users are an improvement of the sleep-wake-rhythm, to direct attention in a timely manner, to support the structure of daily activities and to support spatio-temporal orientation. These effects will be reached by using different light intensities, colour temperatures, light cues, light scenes and light signals. The lighting system is designed to equip a whole flat with four rooms: bedroom, living room, bathroom and kitchen and will provide a high-quality light for all the different requirements that appear in those rooms. Beside artificial light, daylight will be used whenever possible. Therefore, daylight sensors will be used to gather information about the current light levels in the different rooms. Movement sensors will help to follow an energy-saving approach and to help a person safely moving around the flat by providing orientation- and guiding-light. The PETAL – lighting systems allows to create infinitely many different rules with the Rule Editor and therefore can be used for many different situations and needs that might appear in the end-users' home.

In conclusion, the PETAL - Lighting System is an adaptable lighting system that represents a first step towards an adaptive lighting solution in private homes for elderly with MCI. In connection with the PETAL platform, a flexible solution was created that is adaptable to a great variety of requirements that can occur in this setting. Further development that integrates automatic algorithms that produces necessary lighting rules because of gathered information from sensors can be the next step towards an optimized, adaptive lighting solution.

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